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ON THE FREQUENCY DEPENDENCE OF THE ELECTRIC PARAMETERS OF ROCK

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Propagation of VLF Waves

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On the frequency dependence of the electric parameters of rock.

I. Introduction

In our Annual Report Nr. 4 [1] it was shown that the results of the measurement of ε' and ε'' on rock specimens are well reproducible by K.W. Wagner's theory [2] , with the specimens being saturated with water but partially. The results obtained on saturated rock specimens and those obtained on solid rock, however, could not be reproduced by the above theory. In the present paper, the basic difference between the conduction mechanism in rock partially saturated with water and that in saturated rock shall be described. The required measurements were again made with the dolomite specimen D III used in [1] and by means of the same measuring device; in order to make the measurements more general, other rock samples were also used (new red sandstone, granite and zinc blende). Since the studied types of rock yielded largely uniform results of measurement, the essential results of this work shall be explained by the example of specimen D III.

Another three measurements were made in addition to the six measurements described in [1] . After the termination of measurement 6, the specimen was stored in an atmosphere of average humidity (approximately 30%) for two months and was then moistened by storage in an atmosphere of 100% relative humidity at two different temperature values. Then the measurements 7 and 8 were made. For further increasing the water content, the specimen was then stored in tap water for one week and superficially dried with tissue paper immediately before measurement 9. Storing the specimen in water for another week

caused no further changes in electric values. In order to make measurements on saturated specimens possible also at low frequencies, the measurement range of the bridge had to be extended. This was achieved by an additional connection of a capacity decade and a resistance decade to the bridge.

II. Results of the measurements on partially saturated specimens (Number 1 - 8)

In addition to the measurements Nr. 1 - 6 evaluated in [1], the constants of Wagner's theory were determined for the measurements 7 and 8. Table 1 contains the results of evaluation of all eight measurements in correspondence with increasing values of humidity. A graphic representation of the table is shown in Figs. 1a and 1b.

The quantities b and f_m were clearly found to depend on the humidity (Fig. 1a). b and f_m increase with the water content of the specimen; this means that the frequency at which the maximum losses occur is shifted toward higher values and that the frequency range in which losses occur at all becomes smaller.

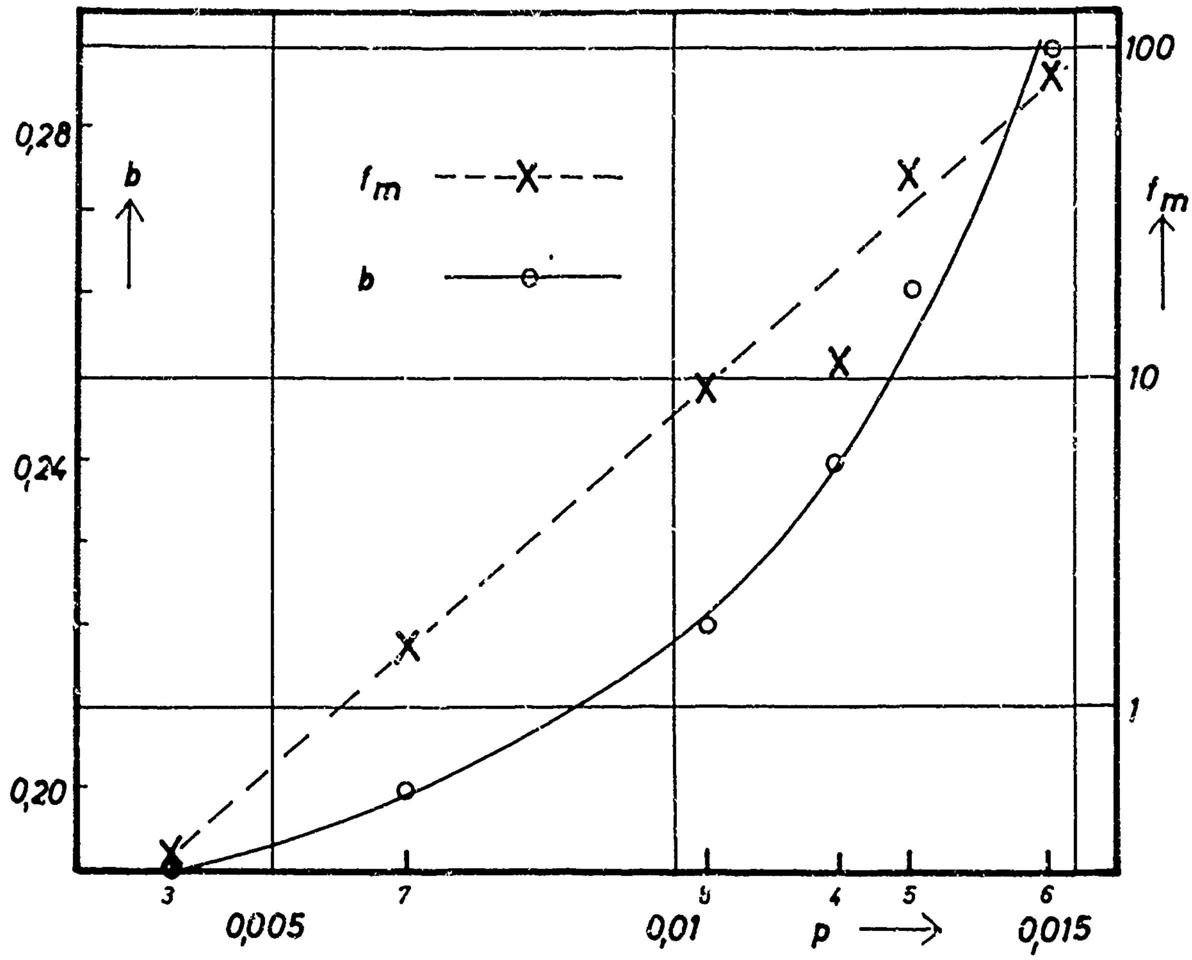
Considerable changes were also observed for ε_∞ and k owing to the different water content in the specimen, a clear relation, however, could not be observed (Fig. 1b). A comparison of ε_∞ with the measured values of the dielectric constant (Ref. [1]) shows that the value of ε_∞ which was determined by Wagner's theory in almost all measurements is larger than the value of ε' at the maximum frequency; this, however, must be incorrect, since ε_∞ is the smallest possible value of ε'. On the whole, this deviation is due to the poor accuracy

of the applied graphical method. For calculating k from the product $\varepsilon_\infty \cdot k$, we therefore used the value $\varepsilon_{\infty\ exp}$ (= ε' at maximum frequency of measurement), not that ε_∞ which was obtained from the graphical evaluation. It is striking that $\varepsilon_{\infty\ exp}$ of the measurements 7 and 8 are smaller than in the other measurements. The reason for this fact could not be explained; it was found however that the long storage of the specimens before the measurements 7 and 8 caused a certain change in dielectric constant, whereas the constants which are decisive for the frequency trend of ε'' remained unaffected (Ref. [3]).

In [1] it has already been said that the good agreement of the experimental data with the values calculated by Wagner's expressions suggests that in the frequency region in question, the dielectric losses observed on the partially moistened rock specimen can be explained by polarization phenomena. For explaining the polarization phenomena satisfactorily, however, a distribution of relaxation times about a prevailing value must be assumed owing to the complex nature of rock.

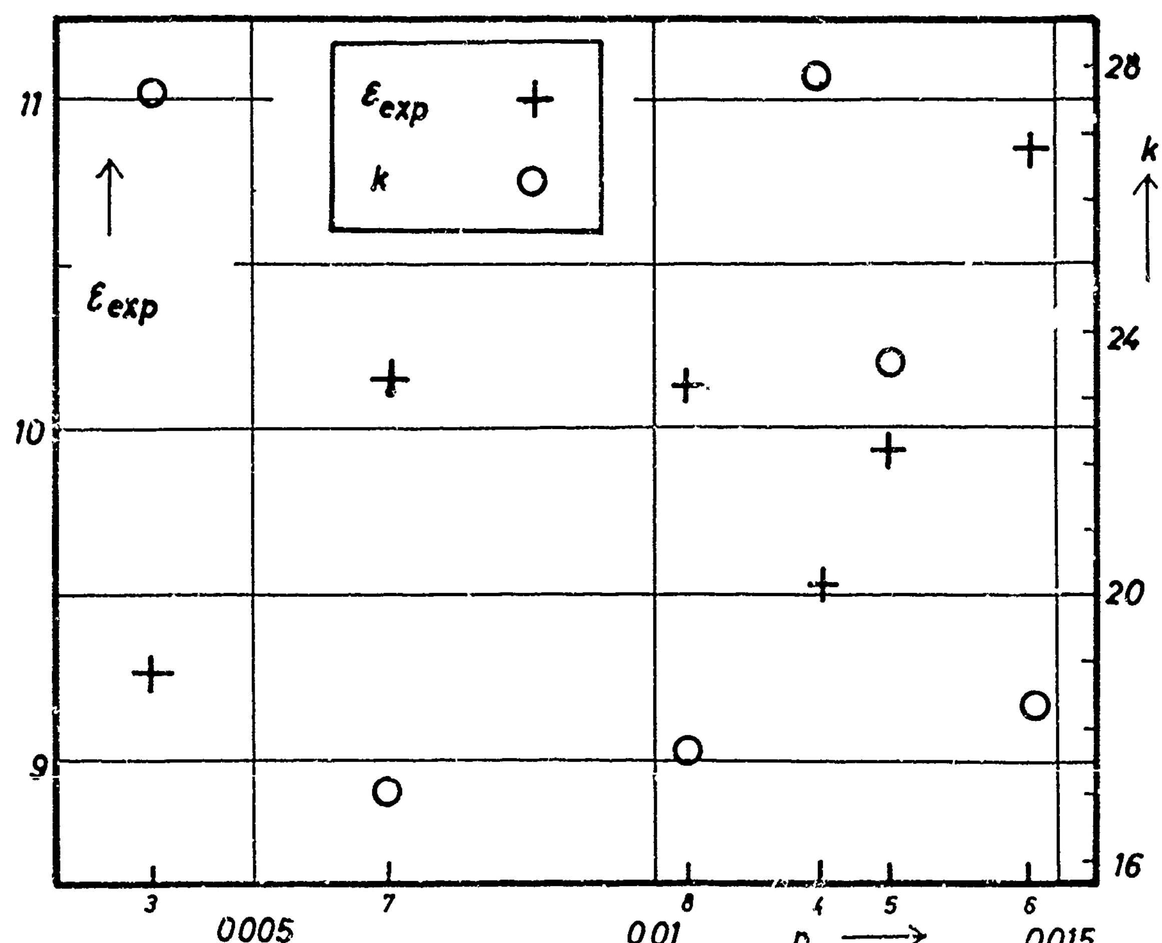
III. Results of the measurement on the saturated specimen (Nr.9)

The result of measurement 9 which was made on a specimen largely saturated with water, cannot be represented by Wagner's expressions (Figs. 2 and 3, curve A). The diagram shows that the frequency trend characteristic of Wagner's expressions does not occur. The curve for ε'' has the same slope in the entire frequency region in question, without showing a maximum; at low frequencies, ε' shows no asymptotic approximat-



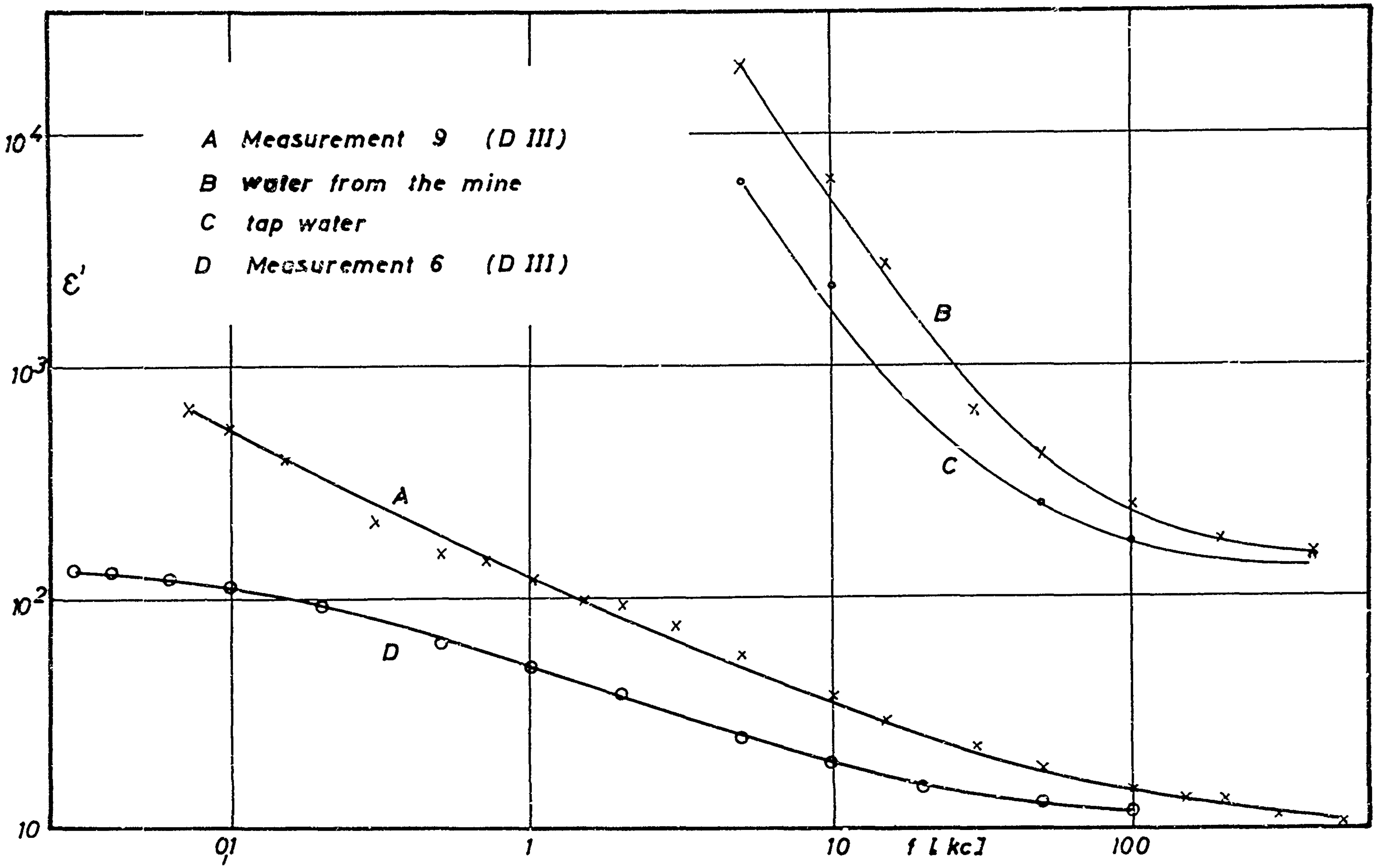
0,28
0,24
0,20
b
f_m
100
10
1
3
7
9
4
5
6
0,005
0,01
0,015
p

FIG. 1 a



11
10
9
ε_{exp}
k
28
24
20
16
3
7
8
4
5
6
0,005
0,01
0,015
p

FIG. 1 b



A Measurement 9 (D III)
B water from the mine
C tap water
D Measurement 6 (D III)
ε'
10^4
10^3
10^2
10
0,1
1
10
100
f [kc]
A
B
C
D

FIG. 2

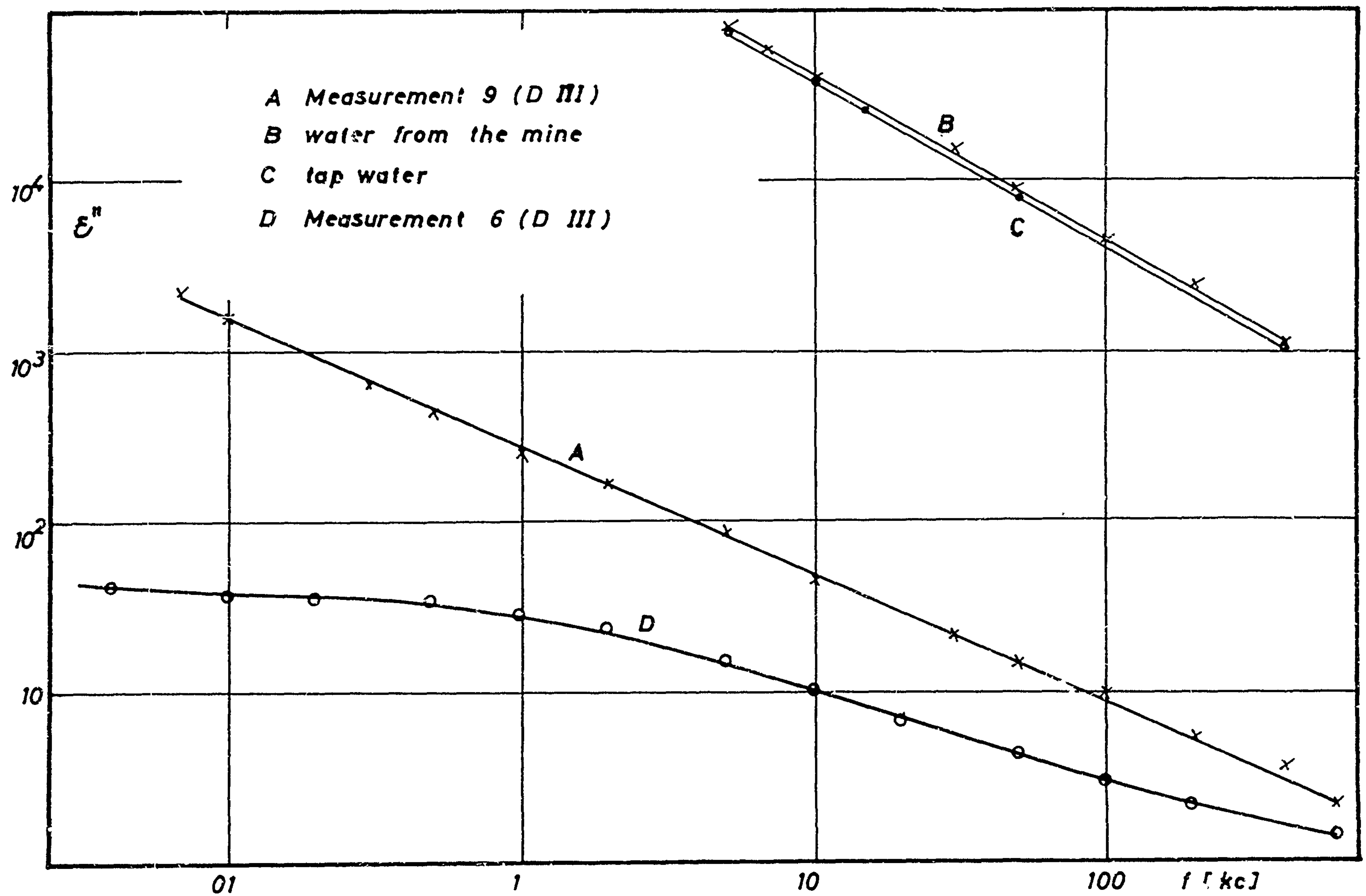
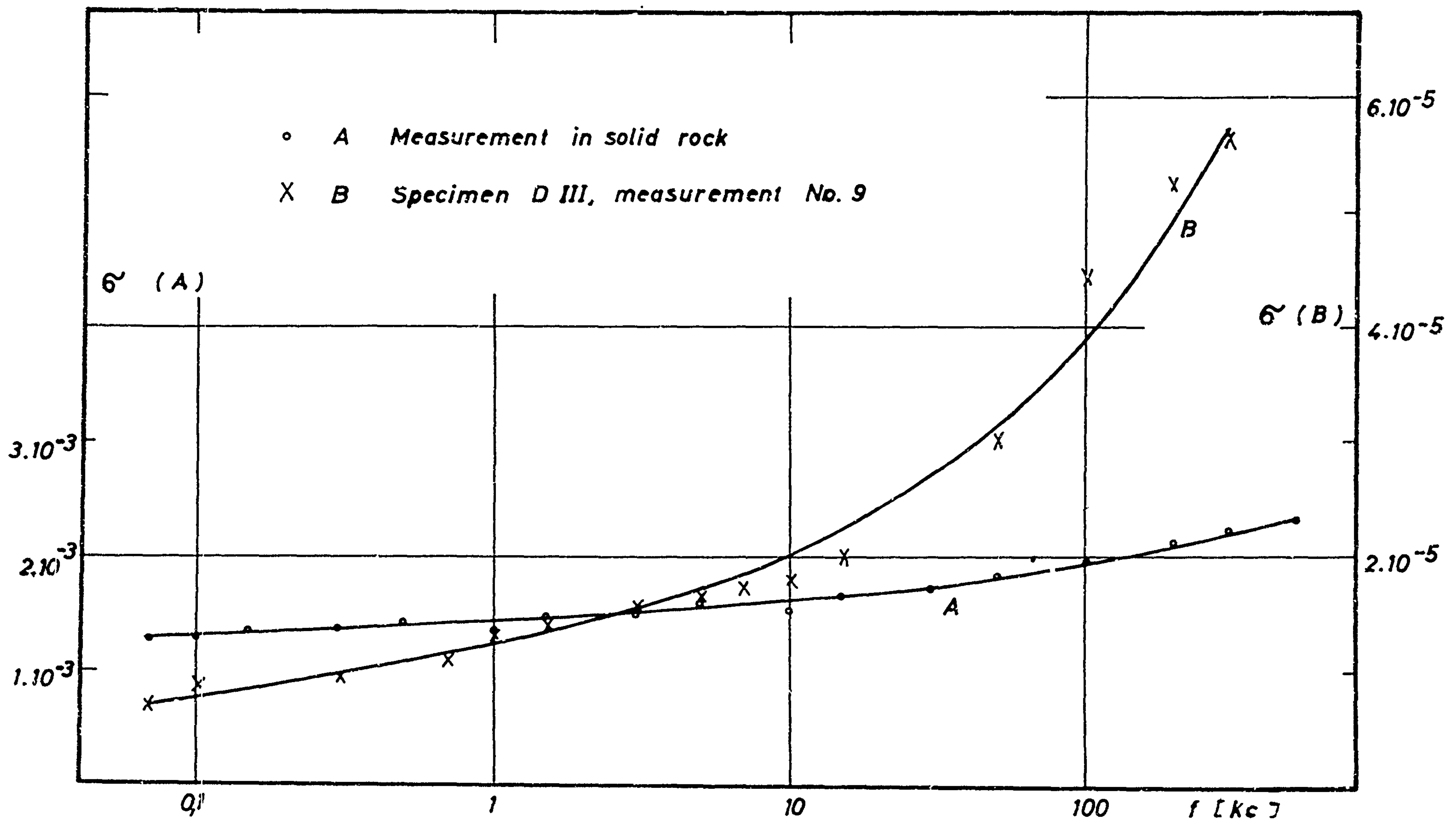

A Measurement 9 (D III)
B water from the mine
C tap water
D Measurement 6 (D III)
ε''
10⁴
10³
10²
10
01
1
10
100
f [kc]
A
B
C
D

FIG. 3



A Measurement in solid rock
B Specimen D III, measurement No. 9
б (A)
б (B)
6.10^-5
4.10^-5
2.10^-5
3.10^-3
2.10^-3
1.10^-3
0,1
1
10
100
f [kc]
A
B

FIG. 4

ion to ε_0. Since the assumption that the properties of the contained water are decisive for the electric data of the specimen was quite evident, ε' and ε'' of water were measured with the same instrument. The result is also shown in Figs. 2 and 3. Curve B holds for water from the mine of Gertraudi, curve C holds for tap water. Furthermore, theresult of measurement 6 is also shown for comparison (curve D).

The values of ε' and ε'' of the mixed body (measurement 9) lie between the values of its components. Despite the small portion by volume of water ($\approx$ 0.55%), the frequency dependence of the two quantities is similar to the frequency dependence of these two quantities for water. This fact and the absence of the frequency dependence typical of Wagner's theory lead to the conclusions that the occurring losses are no longer caused by dielectric polarization with the pore volume being largely filled with water, but that the losses here are conduction losses, and that the charge carriers can migrate through the rock without local restrictions. Losses of this type should therefore better be called "DC-conduction losses" although this expression has hardly been used in publications so far. These losses are inversely proportional to the frequency. In solids, they usually contribute considerably to the total losses only at very small frequencies (Ref. [4] and [5]).

IV. Measurement in solid rock

The conductivity of rock as dependent on the frequency was measured also in solid rock according to the principle of measurement described in [1] . One result of measurement is shown in Fig. 4 together with the result of measurement 9 on

specimen D III which has already been discussed. In the diagram it should be noted that the scale of the result of specimen measurement is shifted upward by 2 decades. The measurement in solid rock shows a good agreement with the results described in [6] and [7] as regards the value and the frequency dependence. Figure 4 shows that the change of the conductivity value with the frequency is much lower in the measurement on solid rock than it is on the specimen. At low frequencies, σ is consistent with the DC value measured at the same point. This agreement was observed at various points in the mine of Gertraudi.

The conductivity measurements on the specimens made by the method described are all one or two decades lower than the values measured on solid rock. Since the electric data of the water used for saturating the specimens differ but slightly from those of the water from the Gertraudi mine, this deviation suggested that the original degree of saturation of the specimens could not be restored by putting them into water. The same frequency dependence obtained for specimens thus saturated and for solid rock showed the same conduction mechanism which differs from the mechanism found for partly moistened specimens. For these specimens, the data of measurement are easy to explain by polarization phenomena, the frequency dependence of saturated rock - for measurements on specimens as well as on solid rock - can be well explained by the assumption that in the studied frequency region conduction losses constitute the major portion of the total dielectric losses.

Table 1

Specimen D III, C_o = 2.65 pf, d = 6.7 mm.

Number of measurement	Weight of specimen	p	b	f_m	ε_∞	$\varepsilon_\infty \cdot k$	$\varepsilon_{\infty exp}$	k
1	34.9518	0	≈0.10					
2	34.9523	0.00143	≈0.12	≈0.017			9	
3	34.9531	0.00372	0.19	0.36	9.2	256	9.3	27.6
7	34.9542	0.00687	0.20	1.49	17.8	174	10.2	17.0
8	34.9554	0.0103	0.22	9.2	10.0	180	10.2	17.6
4	34.9560	0.0120	0.24	11	11	268	9.6	27.9
5	34.9563	0.0129	0.26	41	16	235	10	23.5
6	34.9569	0.0146	0.29	81	17	200	10.9	18.3
9	35.0157	0.183					10.4	

Abstract

Statements on the conduction mechanism in rock and its dependence on the water content are derived from the frequency trend of ε' and ε'' measured on specimens at different water contents and on solid rock. The different results of measurements on specimens and on solid rock are discussed.

References

[1] Annual Report Nr. 4

[2] K.W. WAGNER, Zur Theorie der unvollkommenen Dielektrik. (On the theory of incomplete dielectrics) Annalen der Physik, Band 40, 817 - 855

[3] KELLER and LICASTRO, Dielectric constants and electrical resistivity of natural state cores, Geological Survey Bulletin 1052-H.

[4] J.M. STEVELS, Handbuch der Physik XX, The electric properties of glass.

[5] LIDIARD, A.B., Ionic conductivity, Handbuch der Physik XX, p 311 - 324.

[6] CARSON K.H. TSAO, Investigation of electrical characteristics of rock medium on Cape Cod. AFCRS - 64 - 1.

[7] CARSON K.H. TSAO, Investigation of electrical characteristics of rock medium in northern.New York State. AFCRL - 64 - 99 .